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1 Method and apparatus for substrate handling and printing

2

3 The present invention relates to the field of printing,
4 and in particular to the printing of large number of
5 substrates.

6

7 Ink jet printheads can be used to position spots of
8 liquids, for example biological samples, on substrates
9 such as glass slides. An important application of this
10 technique is the manufacture of DNA microarrays.

11

12 When manufacturing a microarray, it is normally required
13 to print one, two, three or more spots of each liquid
14 onto each of a large number (tens to hundreds) of
15 substrates. Typically, there will be a very large number
16 (hundreds to tens of thousands) of different liquids to
17 be printed onto the substrates, so the printing process
18 may be lengthy.

19

20 The cleaning of the printhead before the introduction of
21 the next set of liquids takes time, and therefore the
22 once a set of liquids has been introduced into the

1 printhead, they should be printed onto all the slides
2 before another set of liquids is loaded.

3

4 Patent application WO 02/11889 discloses a method whereby
5 an ink jet printhead having multiple chambers, each
6 associated with a nozzle, can be used to print multiple
7 different liquids at the same time. The printing can be
8 carried out without cross-contamination between the
9 liquids, despite the fact that the chambers are connected
10 by one or more manifolds internal to the printhead. The
11 liquids are introduced via contiguous groups of nozzles
12 into the associated chambers and printed before they have
13 time to mix by diffusion. Handling multiple liquids
14 therefore offers the possibility of reducing the time
15 taken to do the considerable amount of printing required
16 in the production of DNA microarrays.

17

18 However, if a large number of slides is to be printed,
19 their area is too large to allow them to be arranged in a
20 plane for easy access during printing. It is therefore
21 only practical to arrange smaller groups of the slides
22 for printing. Since the slides do not occupy much
23 volume, it is convenient to store the slides in a
24 multilayer stack. However, the transfer into and out of
25 storage inevitably occupies some time, conflicting with
26 the need to minimise manufacturing time.

27

28 It would therefore be desirable to provide a method and
29 apparatus for handling and printing substrates that
30 obviate or at least mitigate some of the drawbacks of
31 conventional systems.

32

1 It is one aim of an aspect of the invention to provide a
2 method for loading and unloading substrates to printing
3 apparatus in an efficient and rapid manner.

4

5 It is a second aim of an aspect of the invention to
6 provide apparatus for loading and unloading substrates to
7 printing apparatus in an efficient and rapid manner.

8

9 Further aims and objects of the invention will become
10 apparent from a reading of the description.

11

12 According to a first aspect of the invention, there is
13 provided apparatus for transferring substrates to and
14 from a printer, comprising:

- 15 - a first storage unit for storing substrates prior to a
16 printing operation, the first storage unit having a
17 plurality of vertically stacked substrate supports;
- 18 - a platen for receiving a substrate from said first
19 storage unit, aligning the substrate with a printhead
20 prior to a printing operation, and displacing the
21 substrate subsequent to a printing operation to an
22 unloading position;
- 23 - a second storage unit for storing substrates subsequent
24 to said printing operation, the second storage unit
25 having a plurality of vertically stacked substrate
26 supports;
- 27 - wherein the first and second storage units are movable
28 vertically with respect to the platen, and in use,
29 relative vertical movement of the first storage unit
30 and the platen transfers a substrate from the supports
31 of the first storage unit to the platen, and relative
32 vertical movement of the second storage unit and the

1 platen transfers a substrate from the platen to the
2 supports of the second storage unit.

3

4 Preferably, the vertically stacked substrate supports of
5 the first and second storage units are arranged to
6 support substrate-handling trays for holding a plurality
7 of substrates.

8

9 Preferably, the platen receives a substrate-handling tray
10 from the first storage unit, the substrate being held on
11 said substrate handling tray.

12

13 The substrate handling tray may extend lengthways across
14 the width of the platen, the length of the tray being
15 greater than the width of the platen.

16

17 Preferably, the first and second storage units are frames
18 defining an interior cavity, into which the platen
19 extends.

20

21 According to a second aspect of the invention, there is
22 provided a method for transferring substrates to and from
23 a printer, comprising the steps of:

24 - imparting relative vertical movement between a first
25 storage unit for storing substrates and a platen, the
26 first storage unit having a plurality of vertically
27 stacked substrate supports, thereby transferring a
28 substrate from the supports of the first storage unit
29 to the platen;

30 - aligning the substrate with a printhead;

31 - printing on the substrate;

32 - displacing the substrate to an unloading position;

1 - imparting relative vertical movement between a second
2 storage unit for storing substrates and the platen, the
3 second storage unit having a plurality of vertically
4 stacked substrate supports, thereby transferring a
5 substrate from the platen to the supports of the second
6 storage unit.

7

8 According to a third aspect of the invention, there is
9 provided a method for printing substrates on a platen,
10 the method comprising the steps of:

- 11 - printing a substrate by imparting linear movement to
12 the printhead, thereby causing the printhead to
13 traverse the substrate in a first direction, whilst
14 simultaneously transferring a further substrate between
15 the platen and a substrate storage unit;
- 16 - aligning the second substrate tray with the printhead,
17 whilst reversing the direction of motion of the
18 printhead;
- 19 - printing the substrates held on a second substrate tray
20 by imparting linear movement to the printhead, thereby
21 causing the printhead to traverse the substrates in a
22 second direction opposite to the first.

23

24 Preferably, the transfer of a substrate between the
25 platen and the substrate storage unit is carried out by
26 imparting relative vertical movement between a substrate
27 storage unit and the platen, the storage unit having a
28 plurality of vertically stacked substrate supports.

29

30 According to a fourth aspect of the invention, there is
31 provided a method for printing substrates on a platen,
32 the method comprising the steps of:

- 1 - printing a substrate by imparting linear movement to
2 the printhead, thereby causing the printhead to
3 traverse the substrate in a first direction;
4 - transferring a further substrate between the platen and
5 a substrate storage unit;
6 - aligning the further substrate with the printhead,
7 whilst reversing the direction of motion of the
8 printhead;
9 - printing the substrates held on a second substrate tray
10 by imparting linear movement to the printhead, thereby
11 causing the printhead to traverse the substrates in a
12 second direction opposite to the first.

13

14 According to a fifth aspect of the invention, there is
15 provided a method for printing substrates on a platen,
16 the method comprising the steps of:

- 17 - printing a substrate by imparting linear movement to
18 the printhead, thereby causing the printhead to
19 traverse the substrate in a first direction, whilst
20 simultaneously transferring a further substrate between
21 the platen and a substrate storage unit;
22 - aligning the second substrate tray with the printhead;
23 - reversing the direction of motion of the printhead;
24 - printing the substrates held on a second substrate tray
25 by imparting linear movement to the printhead, thereby
26 causing the printhead to traverse the substrates in a
27 second direction opposite to the first.

28

29 Preferably, the steps of the method are repeated.

30

31 There will now be described, by way of example only,
32 various embodiments of the invention with reference to
33 the following drawings, of which:

1

2 Figure 1 is a plan view of apparatus according to an
3 embodiment of the invention;

4

5 Figure 2 is a front view of the apparatus of Figure
6 1;

7

8 Figure 3 is a side view of the apparatus of Figure
9 1;

10

11 Figure 4 shows a side view of the apparatus and a
12 table useful for explaining a method in accordance
13 with an embodiment of the invention;

14

15 Figure 5 shows a table useful for explaining a
16 method in accordance with an alternative embodiment
17 of the invention.

18

19 Referring firstly to Figures 1 and 2, the apparatus
20 generally depicted at 10 includes a platen 12, four cages
21 13a to 13d, and a linear rail 14. Each cage is a
22 rectangular metal frame 15 having a series of vertically
23 stacked substrate supports in the form of inwardly
24 protruding ledges 16. The cages are shaped to receive a
25 number of slide trays 17, each slide tray holding a
26 linear array of slides to be printed. Each slide tray 17
27 is oriented lengthways across the width of the platen 12,
28 and the length of the trays is greater than the width of
29 the platen. The platen 12 is therefore able to extend
30 into a central cavity defined by the frame of the cage.

31

32 The platen 12 has four positions for receiving slide
33 trays. Above one of the positions is a linear rail 14

1 along which the printhead 19 can be moved in a
2 reciprocating motion following a trapezoidal velocity
3 profile. The acceleration and deceleration associated
4 with the changing of direction of the printhead at each
5 end occurs beyond the end of the trays. The printhead
6 axis is positioned with two cages 13 on either side. A
7 suitable printhead is the XaarJet XJ126R.

8

9 The arrangement for the slides within a tray is a linear
10 array of, say, twenty five slides 18 with their short
11 edges parallel to the long axis of the trays and the long
12 edges of adjacent slides facing one another. This
13 minimises the time occupied travelling over each slide.
14 A convenient pitch for the slides is 27 mm, which allows
15 space for mechanisms to hold the slides, and fits in with
16 the possibility of using two or more printheads, line
17 astern. A printhead such as the XaarJet XJ126R can be
18 set at a pitch of 54 mm, which works well with the 9 mm
19 pitch of the well-plates from which the liquids are
20 usually obtained..

21

22 As shown in Figure 2 ledges 16 of the cages above the
23 platen 12 are filled with trays 17 (all but one shown in
24 dotted lines for clarity), while the ledges below are
25 empty. The cage is shown in a position where it has
26 moved downwards, so that the tray is brought into contact
27 with the platen. A slight further downward movement of
28 the cage causes the tray to come to rest on the platen,
29 freeing the trays from the ledges of the cage on which it
30 was resting and depositing it onto the platen. A
31 subsequent fore-aft movement of the platen will carry the
32 tray to a position outside the frame of the cage.

33

1 Figure 3 shows the four cages 13a to 13d from a side
2 view. Cages 13a and 13c are loaded with slide trays (not
3 shown), and are positioned above the platen. In use,
4 these upper cages will descend in stages from the high
5 positions, depositing trays onto the platen in readiness
6 for printing. In contrast, cages 13b and 13d are empty
7 of trays, and are initially located in low positions
8 below the platen. Cages 13b and 13d ascend from these
9 low positions, unloading trays from the platen after
10 printing.

11

12 The platen 12 is shown in one of its four possible
13 positions, in which it spans four of seven equally sized
14 regions of space. The other positions are shown by
15 dotted lines 21. The two extreme positions are outside
16 of the boundary of the cages 13.

17

18 The operation of the apparatus will now be described with
19 reference to Figure 4. The Figure shows the apparatus
20 from a side view, and a table useful for understanding
21 the handling and printing process.

22

23 Each row of the table represents a different time
24 interval during the process. Time passes from the top of
25 the table to the bottom. The first four rows represent a
26 start-up sequence for loading and printing the first
27 trays, and the bottom four rows represent an end sequence
28 for dealing with the last trays. The middle four rows
29 are repeated for as many iterations as is necessary for
30 printing the entire batch of slides.

31

32 Each column of the table corresponds to a possible
33 position of the platen. The platen occupies four

1 adjacent positions within the seven. The actual position
2 of the platen at any time is indicated by the shaded
3 portions of the table.

4

5 The apparatus is initially set up as follows: the two
6 cages 13a, 13c are in their uppermost positions, fully
7 occupied by trays of slides; cages 13b, 13d are in their
8 lowest positions, empty. The platen is initially empty.

9

10 First a startup sequence is performed, as represented by
11 rows R1 to R4 of Figure 4:

12

13 The platen is positioned as illustrated, occupying the
14 third to sixth of the seven regions (counting from the
15 left). The first tray is loaded onto the platen by a
16 downward movement of the right-most cage, cage 13a. As
17 described above, the downward movement of the cage causes
18 the tray to come to rest on the platen, freeing the tray
19 from the ledges of cage 13a and depositing it onto the
20 platen. This action is represented by the word 'load' in
21 the table, underneath the cage in question.

22

23 The platen then moves one pitch to the right placing the
24 tray outside the frame and ledges of cage 13a. A second
25 tray is loaded by cage 13a to a platen position adjacent
26 to the first tray.

27

28 The platen then moves three pitches to the left, so that
29 it occupies the first to fourth positions. Next, the
30 printhead performs its first movement, printing the
31 slides located on the first tray (now located under the
32 printhead rail). This action is represented by the word

1 'print' underneath the printhead in the table of Figure 4
2 at row R3.

3

4 When the printhead has passed the end of the slide tray,
5 the printhead slows down and changes direction. While
6 the printhead is turning round, the platen moves one
7 pitch to the right. The printhead now prints the second
8 of the trays, while moving in the reverse direction.
9 Simultaneously, while the printhead is moving but the
10 platen is stationary, the cage 13c loads a third tray.
11 At the same time, cage 13b unloads the first tray that
12 was printed. This unloading action is effectively the
13 reverse of the loading action. The cage 13c surrounds
14 the tray as it rests on the platen, and the ledges are
15 located underneath the ends of the tray. The cage 13b
16 moves upwards, so that the ledges are brought into
17 contact with the tray, and then lift the tray from the
18 platen. This unloading action is represented in the
19 table of Figure 4 is 'unload'.

20

21 The platen moves one pitch to the right, completing the
22 start-up sequence, and the system enters a central
23 sequence that is repeated as often as is appropriate for
24 the number of trays in the machine.

25

26 The central sequence follows the same principle. Cages
27 13 load and unload trays during printing and when the
28 platen 12 is stationary. The platen moves while the
29 printhead is reversing direction. The central sequence
30 shown, consists of four stages, represented by rows R5 to
31 R8. The apparatus first loads two trays from cages 13a
32 and 13c, unloads one tray onto cage 13b, and prints the
33 tray that is aligned with the printhead. The following

1 two steps respectively involve a print operation and the
2 loading of a new tray from cage 13a, and print operation
3 and an unloading action onto cage 13d. The central
4 sequence therefore prints four trays in four traverses of
5 the printhead. That is, the printhead is busy at every
6 step of the process. The central sequence is repeated as
7 many times as necessary, until the cages 13a and 13c are
8 almost empty of trays.

9

10 Rows R9 to R12 represent an end sequence for handling the
11 remaining trays on the platen 12. At R9, the final tray
12 is loaded onto the platen from cage 13d, the penultimate
13 tray is printed, and a tray is unloaded onto cage 13b.
14 The next steps involves the printing of the final tray,
15 and the subsequent unloading of the trays onto cage 13d.

16

17 The whole of the above-described operation consists of a
18 start-up sequence, a number n of repeats of the four-
19 stage central sequence, and an end sequence. The
20 operation results in the printing of a set of liquids
21 held within the printhead onto all $4(n+1)$ trays of slides
22 in the machine. At the end of this operation the trays
23 have been transferred, with reversal of order, from the
24 two loading cages 13a, 13c to the two unloading cages
25 13b, 13d. Cages 13a, 13b were initially in a raised
26 position, but have now descended below the platen,
27 emptying of trays. Cages 13b, 13d, initially below the
28 platen, have ascended filling with trays.

29

30 It is notable that only four out of a total of $4(n+2)$
31 operations do not involve printing, so the printhead is
32 kept busy with great efficiency, particularly if n is
33 substantial.

1
2 When the next set of liquids has been acquired by the
3 printhead, the entire operation is applied in reverse,
4 printing the new set of liquids onto slightly different
5 positions on all the trays of slides. The load cages
6 13a, 13c, which were moving downwards, have now become
7 unload cages moving upwards, and vice versa. The scheme
8 illustrated in the table of Figure 4 has the highly
9 desirable property that every tray is printed with the
10 printhead travelling in the same direction as with the
11 previous set of liquids. This minimises errors due to
12 the time of flight of the drops, as the shifts will in
13 the same direction for all liquids printed onto a given
14 slide. At the end of two complete operations, two sets
15 of liquids have been printed onto all of the slides, and
16 all the cages and trays are back in their original
17 positions.

18
19 Multiple sets of liquids are printed using the same
20 overall operation, alternately in the order given in
21 Figure 4 and in reverse. The positions on the slides of
22 the sets of spots are shifted in the direction of
23 printhead motion by applying different offsets to the
24 triggering electronics each time the printhead performs a
25 series of traverses. After a number of operations, the
26 slides have been filled with spots along the line of
27 travel of the printhead. During the next few operations,
28 the four positions visited by the platen, while still
29 equally spaced at the same pitch, are shifted slightly
30 relative to the previous ones. This causes another row
31 of spots to be printed on the slides. It is necessary
32 for the entire assembly of four cages to occupy a
33 slightly different position for each row of spots. As

1 printing of a large number of liquids proceeds, multiple
2 rows of spots are produced on the slides. Their spacing
3 in the direction of printhead travel is controlled by the
4 timing of printhead triggering, and the spacing
5 perpendicular to printhead motion is determined by the
6 shifts in platen positions. Accuracy of spot positioning
7 is guaranteed by the accuracy of these two motions and by
8 the mechanism whereby trays stored on inaccurately
9 manufactured cages are located precisely on the platen as
10 they are loaded.

11
12 The sequence in the table of Figure 4 prints $4(n+1)$ trays
13 of slides. If the number of trays to be printed is even
14 but not divisible by four, i.e. $4n+2$, the sequence shown
15 in the table of Figure 5 can be used. This sequence
16 appears to be slightly more efficient than that in the
17 table of Figure 4, in that one fewer stage is required at
18 start-up and at the end. However, as explained above, it
19 is highly desirable to guarantee that individual slides
20 are always printed with printhead motion in the same
21 direction. The sequence of Figure 5 will require an
22 extra traverse by the printhead at the outset, and at the
23 end in order for the printhead motion to be consistent.

24
25 It is possible to extend these schemes to handle an odd
26 number of trays or to handle the situation where the last
27 tray is not filled with slides. Thus, any number of
28 slides can be handled, not just a multiple of fifty.

29
30 Other schemes are possible, involving cages which load
31 more than one tray at a time onto the platen; using two
32 or more than four cages; using cages to store both
33 unprinted and printed trays.

1
2 A practical convenience of the proposed four-cage system
3 is that at the outset the two cages closest to the front
4 of the machine can be loaded with trays, and the platen
5 used to transfer the contents of one of them to the rear
6 of the machine as required to start the sequences of
7 Figure 4.

8
9 The present invention provides an efficient means of
10 printing a large number of substrates, by providing a
11 rapid means of storing, retrieving, printing and re-
12 storing slides.

13
14 The arrangement reduces the requirement for reloading the
15 printhead with different liquids. The liquids are
16 valuable and available in small quantities only. The
17 loading of liquids into the printhead is inevitably
18 wasteful in that only a proportion of each liquid is
19 usefully printed. Ink jet printheads produce very small
20 drops, so once liquids are introduced into the printhead,
21 ~~it can print a very large number of spots.~~ The present
22 invention utilises this characteristic of the printheads
23 effectively.

24
25 A further advantage of the invention arises from
26 reciprocating the printhead motion using a one-
27 dimensional transport, and mounting multiple trays on a
28 platen which is capable of movement at right-angles to
29 the printhead motion. The printhead traverses to print
30 the tray which is in the appropriate position on the
31 (stationary) platen; then the platen moves laterally
32 while the printhead is turning round at the end of its
33 stroke, bringing another tray of slides into position

1 underneath the axis of printhead motion. By the time the
2 next printhead stroke takes place, the platen is again
3 stationary. Accurate spot positioning is achieved in the
4 direction of printhead travel by timing of the drop
5 ejection, as disclosed in patent application WO 02/11889,
6 and in the perpendicular direction by precise positioning
7 of the platen.

8
9 The invention therefore minimises the time during which
10 the printhead is not printing.

11

12 An additional advantage of this approach is that larger
13 numbers of trays can be printed than those which fit on
14 the platen: one or more cages can be used to store the
15 trays when they are not being printed, to feed them onto
16 the platen for printing and to remove them afterwards. A
17 number of trays can be stored above each other on shelves
18 in each cage; one or more cages can be moved vertically
19 downwards so as to deposit the trays in turn onto the
20 platen in preparation for printing. One or more other
21 cages, moving vertically upwards, can remove them
22 afterwards. The cages can perform these functions while
23 the platen is stationary, during the printing stroke of
24 the printhead. Thus the loading of trays onto the platen
25 and unloading from it need not add to the time taken to
26 print the overall number of slides in the machine; this
27 scheme is equivalent in speed to a system using an
28 impracticably large platen to hold all the trays.

29

30 A further advantage of this approach is that the cages
31 and their motion need not be precise: if the trays are
32 equipped with location features which engage with
33 matching features on the platen, the act of loading each

1 tray onto the platen ensures its accurate positioning
2 with respect to the platen. The only parameters that
3 need to be accurate are the printhead mounting, its
4 motion, the platen's location features and its motion.
5 Both of these motions are one-dimensional.

6

7 It will be evident to the skilled reader that various
8 changes could be made to the above-described embodiments
9 within the scope of the invention. For example,
10 different numbers of loading and unloading cages could be
11 employed. In addition, one cage could unload trays, and
12 could reload the same trays from the platen after
13 printing. A further arrangement may utilise two cages
14 that simultaneously unload or load two trays at different
15 positions on the platen.

16

17 Various modifications and improvements can be made within
18 the scope of the invention herein intended.
